Structural Loads and Dynamics for the Alpha Magnetic Spectrometer-02

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AMS-02 Critical Design Review
May 13-16, 2003

Introduction

- **Design Loads**
- **Math Models**
- **Static Preload Modeling**
- **Manifest Status**
- **Attach Point Limit Loads Capability Assessment**
- **Orbiter Clearance Assessment**
- **Loads Analyses**

Design Loads for AMS-02 Liftoff and Landing

- **Design load factors were generated for Space Shuttle launch and landing cases**
  - Derived from a preliminary design coupled loads analysis
    - Performed in 1999 using math model available at that time
    - DCLA did not include the nonlinear contribution of the magnet support straps
  - An uncertainty factor of 1.5 was included in the resulting load factors
  - Applicable to USS, vacuum case, cryo-magnet system, helium tank, support straps

Load Case	Nx (g's)	Ny (g's)	Nz (g's)	Rx (rad/sec^2)	Ry (rad/sec^2)	Rz (rad/sec^2)
Liftoff	± 5.7	± 1.6	± 5.9	± 10.0	± 25.0	± 18.0
Nominal and Abort Landing	± 4.5	± 2.0	± 6.5	± 20.0	± 35.0	± 15.0
Contingency Landing (includes He slosh)	± 6.0	± 3.7	± 6.5	± 20.0	± 35.0	± 15.0

- These load factors were used in a nonlinear, static analyses with math model of full payload to derive component interface loads for detailed design and stress analyses
- Several components that are highly influenced by the deformation of the USS have been designed using a combination of primary load factors with enforced displacements at their interface to the USS (upper/lower TOF, TRD, RICH, radiators)

Design Loads for AMS-02 ISS Configuration

- **Primary structure design loads for ISS attached configuration from SSP 57003 Rev A**
  - Used payload-to-PAS interface loads from Table 3.1.1.2.3-2
  - These interface loads used to design the payload attach system (PAS) for AMS-02
  - Remainder of AMS-02 structure is being assessed for these loads, but not expected to be a design drive

Condition	F_x (lb)	F_y (lb)	F_z (in-lb)	M_x (in-lb)	M_y (in-lb)	M_z (in-lb)
1	+420.	+40.	-70.	-4620.	-32370.	-6140.
2	-410.	-50.	+70.	-4770.	+33740.	-10710.
3	-250.	-640.	+120.	+51870.	+19620.	+2610.
4	+250.	+640.	-120.	-51870.	-19620.	-2610.
5	-190.	+100.	-480.	-15800.	+14300.	+3070.
6	+190.	+100.	+490.	-7780.	-14440.	+4370.
7	-520.	-180.	+90.	-14390.	+43410.	-18850.
8	+210.	+510.	-10.	+38990.	-9200.	+25610.

Design Loads for AMS-02 Secondary Structure

- **Design load factors for AMS-02 secondary structure**
  - Components weighing more than 500 pounds use load factors developed specifically for the component as documented in the SVP.
  - Components weighing less than 500 pounds use "simplified design" load factors ("Simplified Design Options for STS Payloads", JSC-20545A, April 1988).

Weight (lb)	Load Factor (g's)
< 20.	40.
20. – 50.	31.
50. – 100.	22.
100. – 200.	17.
200 – 500.	13.

Additional Design Loads for AMS-02

- **Experiment components with large panels assessed for acoustic loads**
  - Honeycomb panels for upper/lower TOF, radiators, and TRD
  - Responses computed with VAPEPS (Vibro Acoustic Payload Environment Prediction System)
  - Load factors modified to account for acoustic effects as needed
- **Helium slosh loads have been assessed and included in primary design loads for contingency landing cases**
- **Magnet forces and eddy current induced loads are being assessed**
- **EVA related loads will be assessed for all external items that have potential crew contact**
  - Crew kick loads, hand hold loads, torque fastener loads
  - EVA not planned, contingency only
- **Shuttle RMS and Space Station RMS grapple fixture loads will be assessed**
- **Orbiter emergency landing loads are bounded by primary structure design load factors** (defined in NSTS-21000-IDD-ISS)

Summary of Design Loads for AMS-02

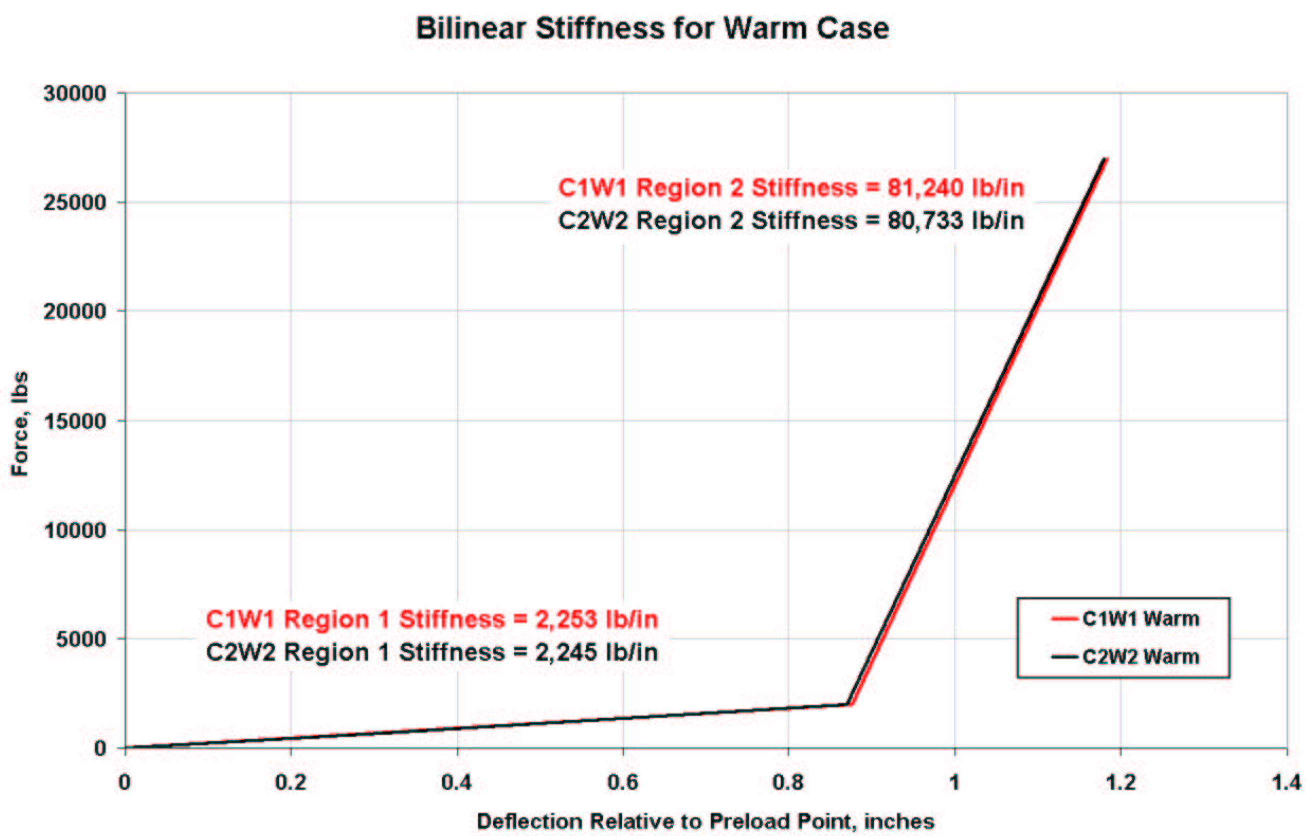
Component	Weight (lb)	Design Loads	Math Model
Unique Support Structure	1592.	Primary structure load factors applied in nonlinear static analysis	Full payload
Vacuum Case	1587.		
Cryo-magnet System	5196.		
Transition Radiation Detector	723.	Primary structure load factors combined with boundary displacements	Individual Components
Upper Time-of-flight	262.		
Lower Time-of-flight	263.		
Ring Imaging Cherenkov Counter	406.		
Thermal Control System (* radiators and radiator mounted crates)	686.*		
Electromagnetic Calorimeter	1407.	Specific load factors per SVP	Individual Components
Tracker	438.		
Anti-coincidence Counter	117.	Secondary structure load factors (17.g's)	Component
TRD Gas Supply System	258.	Secondary structure load factors (13.g's)	Component
Electronic boxes	40. to 80. lb each	Secondary structure load factors	Component
Subcomponents of above items	---	Secondary structure load factors	Component

Math Model for AMS-02 Loads Analysis

- **Math model has been developed/updated based on CAD models from designers**
  - High level of fidelity for all major components
    - USS and vacuum case
    - Magnet, helium tank
    - Experiments (upper/lower TOF, TRD, TRD gas supply, ECAL, radiators, RICH)
  - Nonstructural items and items that are relatively rigid are modeled as lumped masses
  - Model mass properties reflect current assessment from all component developers
  - Current loads model in excess of 360,000 DOF

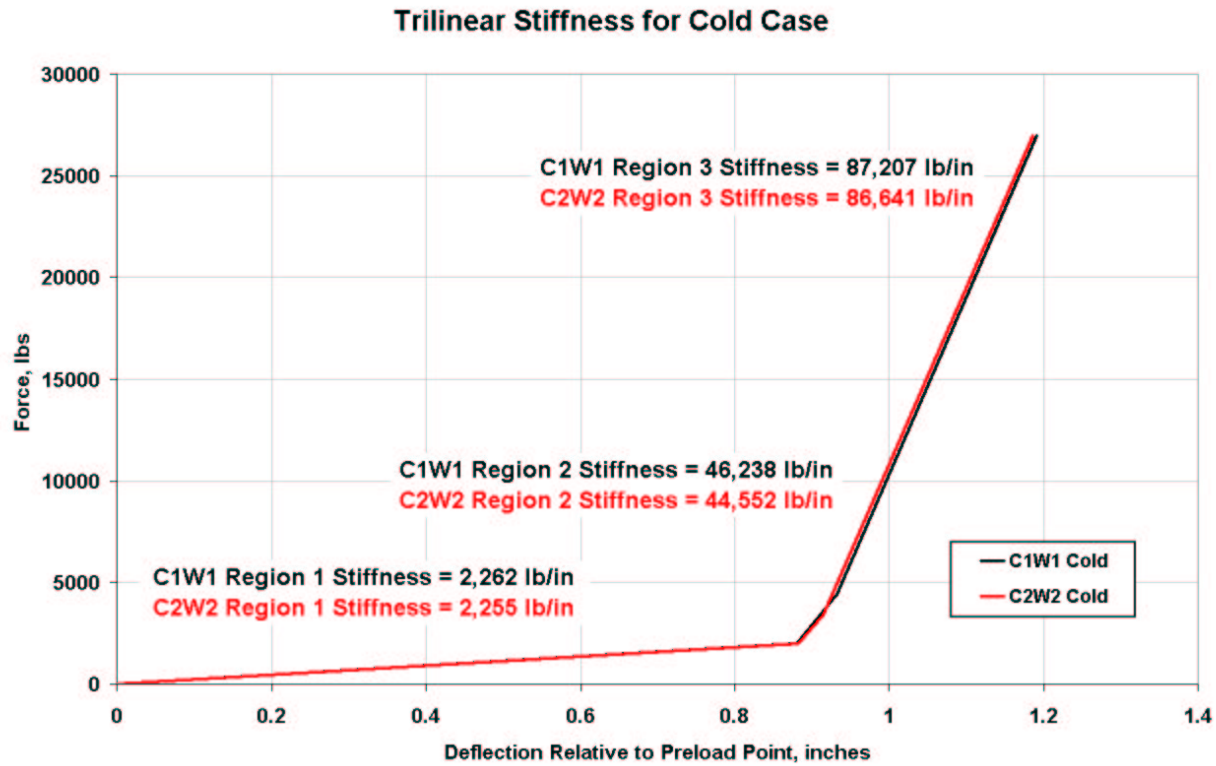
- **Model of magnet support straps account for nonlinearity of this system**
  - Modeled using tension elements with a defined stress-strain relationship
  - Stress-strain relationship in math model is based on physical force-displacements for each strap configuration
    - C1W1 Warm — x-axis strap at room temperature
    - C1W1 Cold — x-axis strap at cryogenic temperatures
    - C2W2 Warm — y-axis strap at room temperature
    - C2W2 Cold — y-axis strap at cryogenic temperatures

Model for Magnet Support Strap



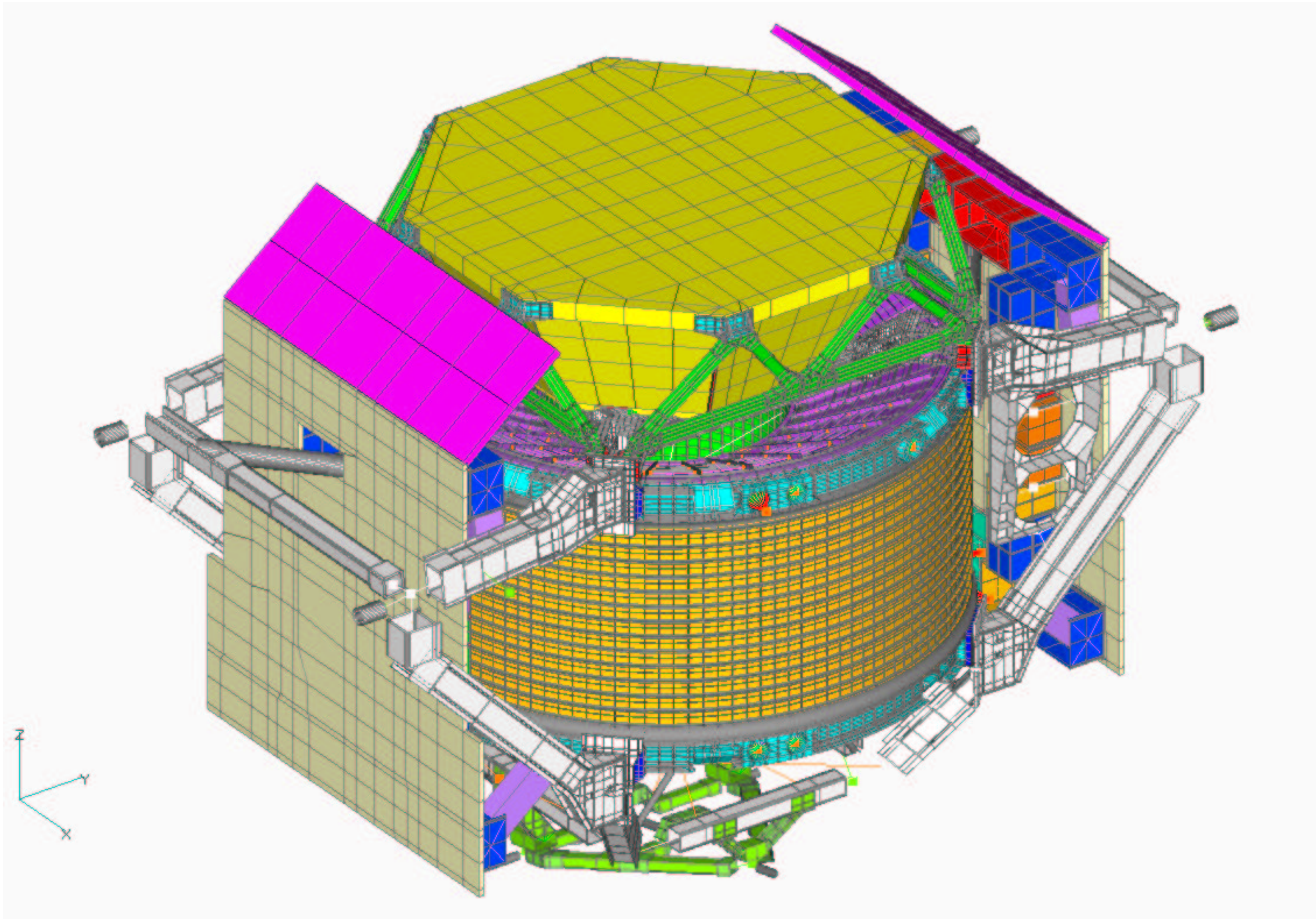
- **Warm strap model used for configurations that assume helium tank is empty**
  - Nominal landing
  - 1-D strap tests

Model for Magnet Support Strap

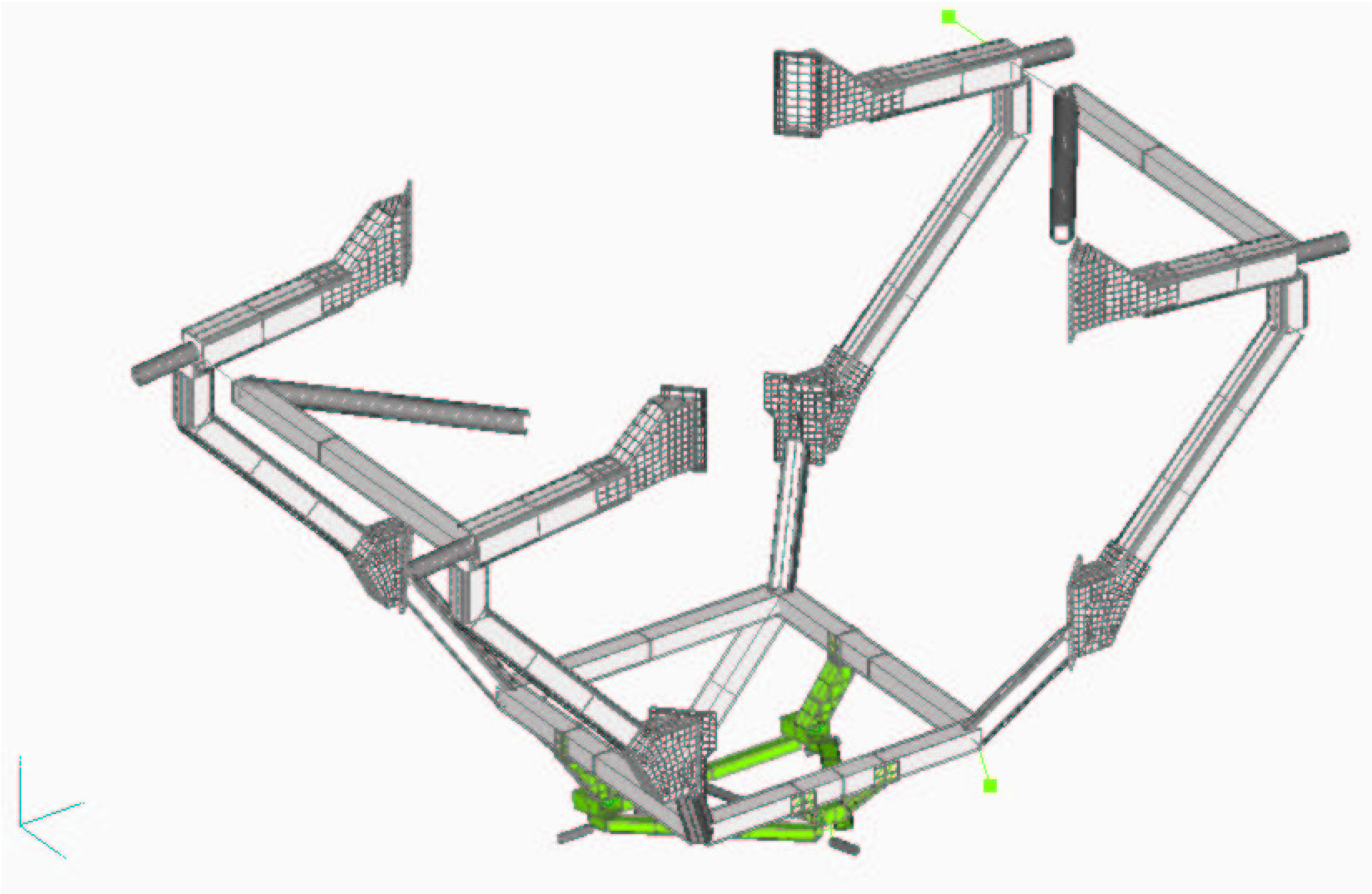


- **Cold strap model used for configurations that assume helium tank is full**
  - liftoff
  - abort landing
  - STA sine sweep and modal tests

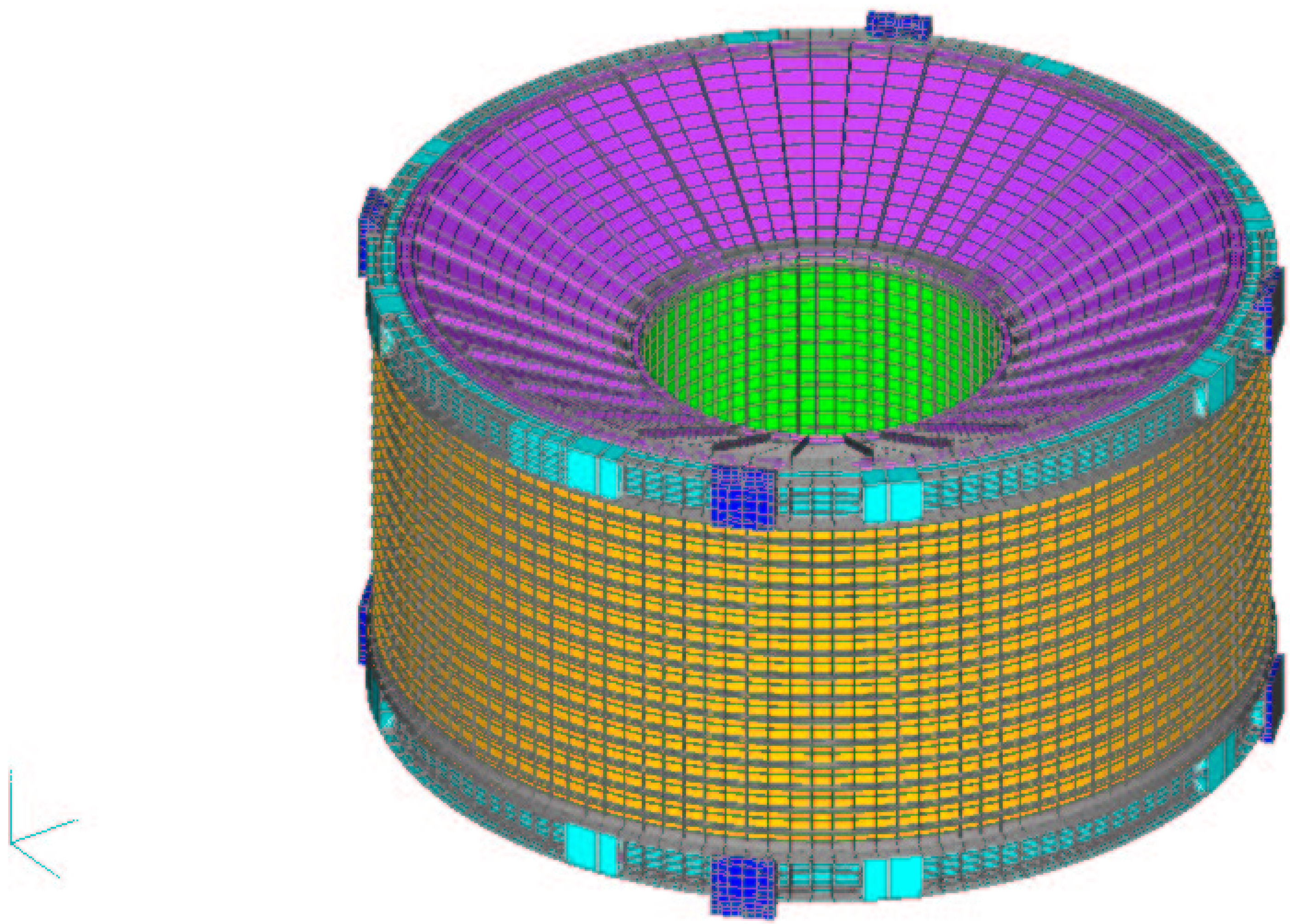
Loads Model of the AMS-02 Payload



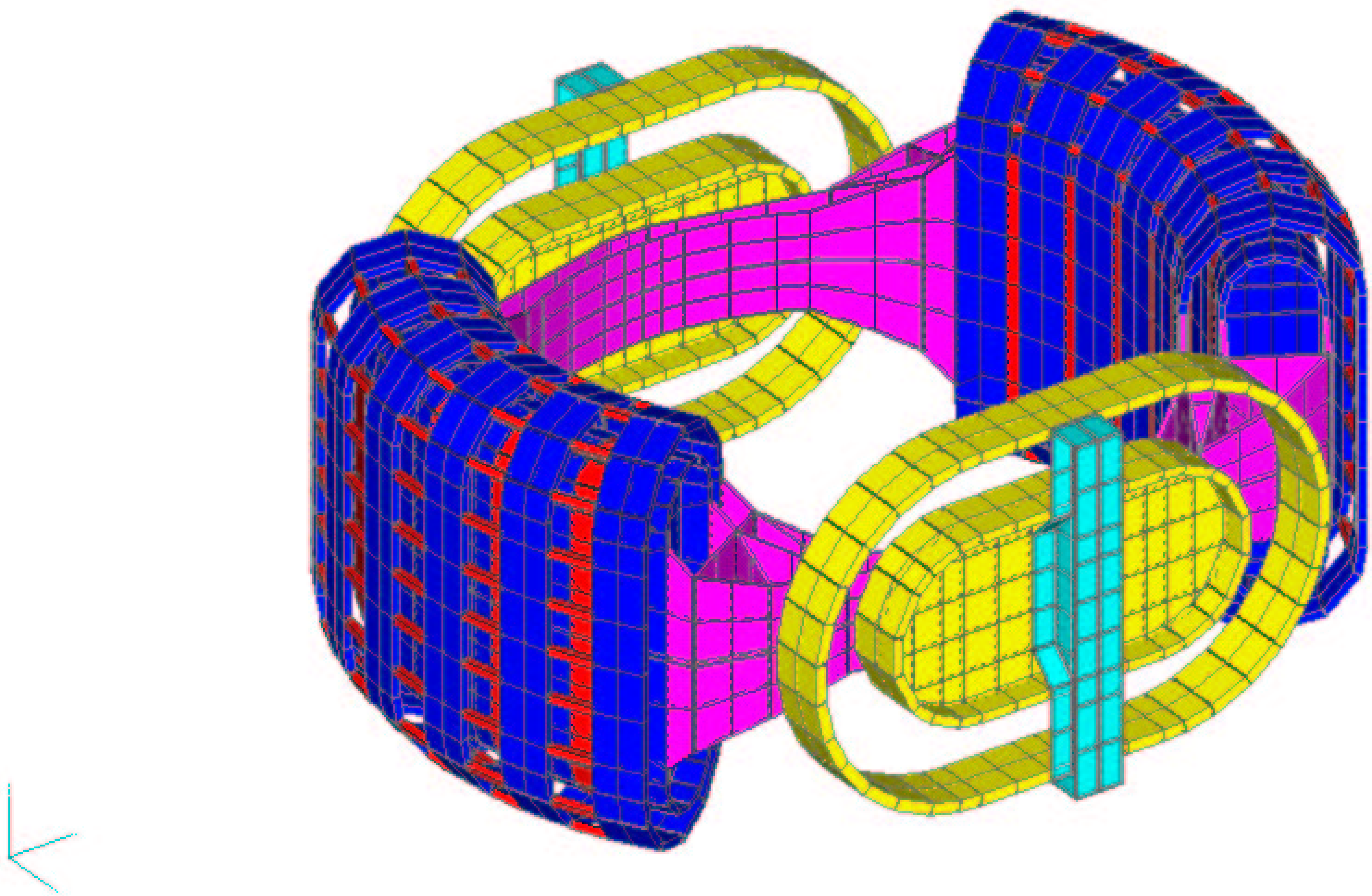
Loads Model of the USS-02



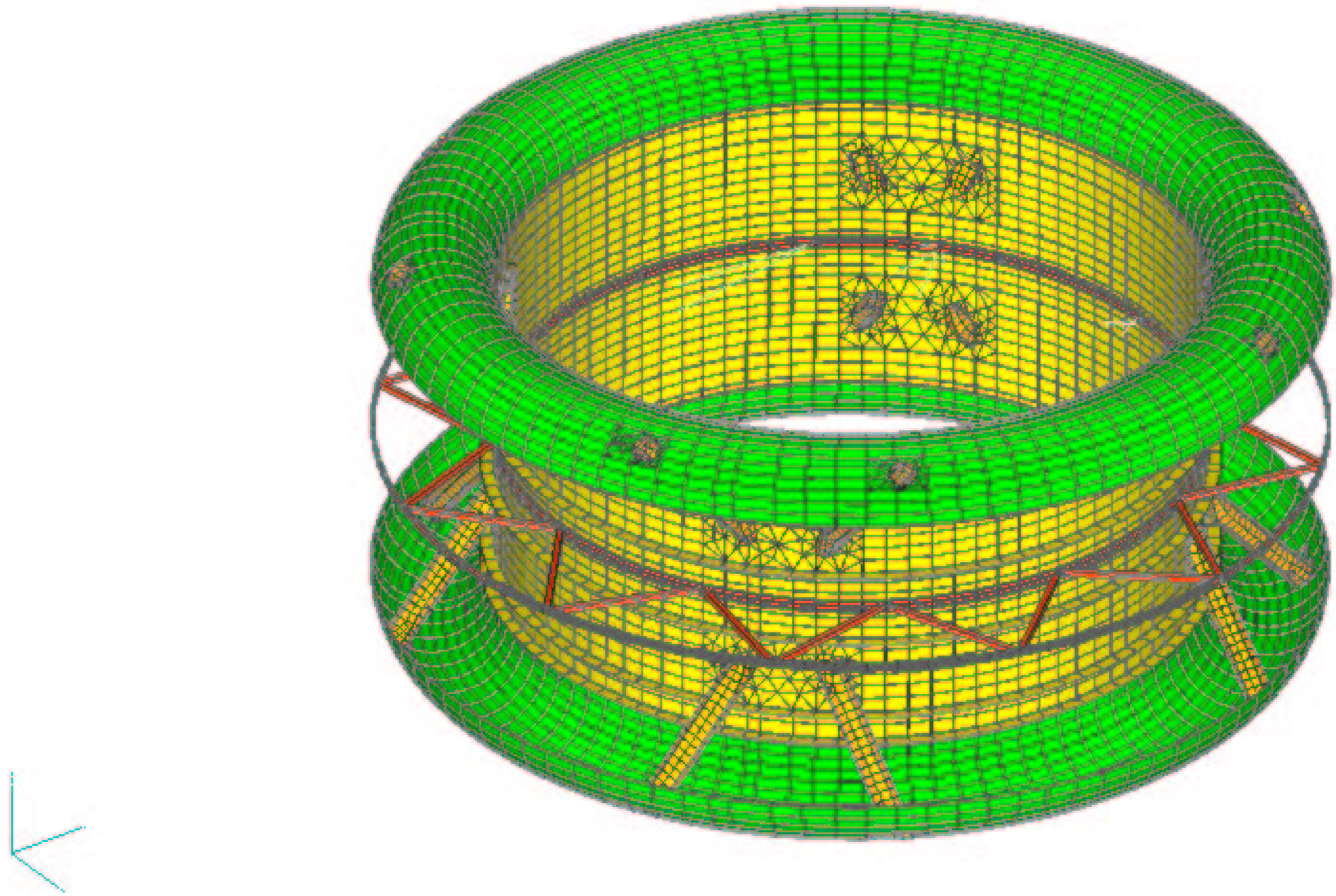
Loads Model of the Vacuum Case



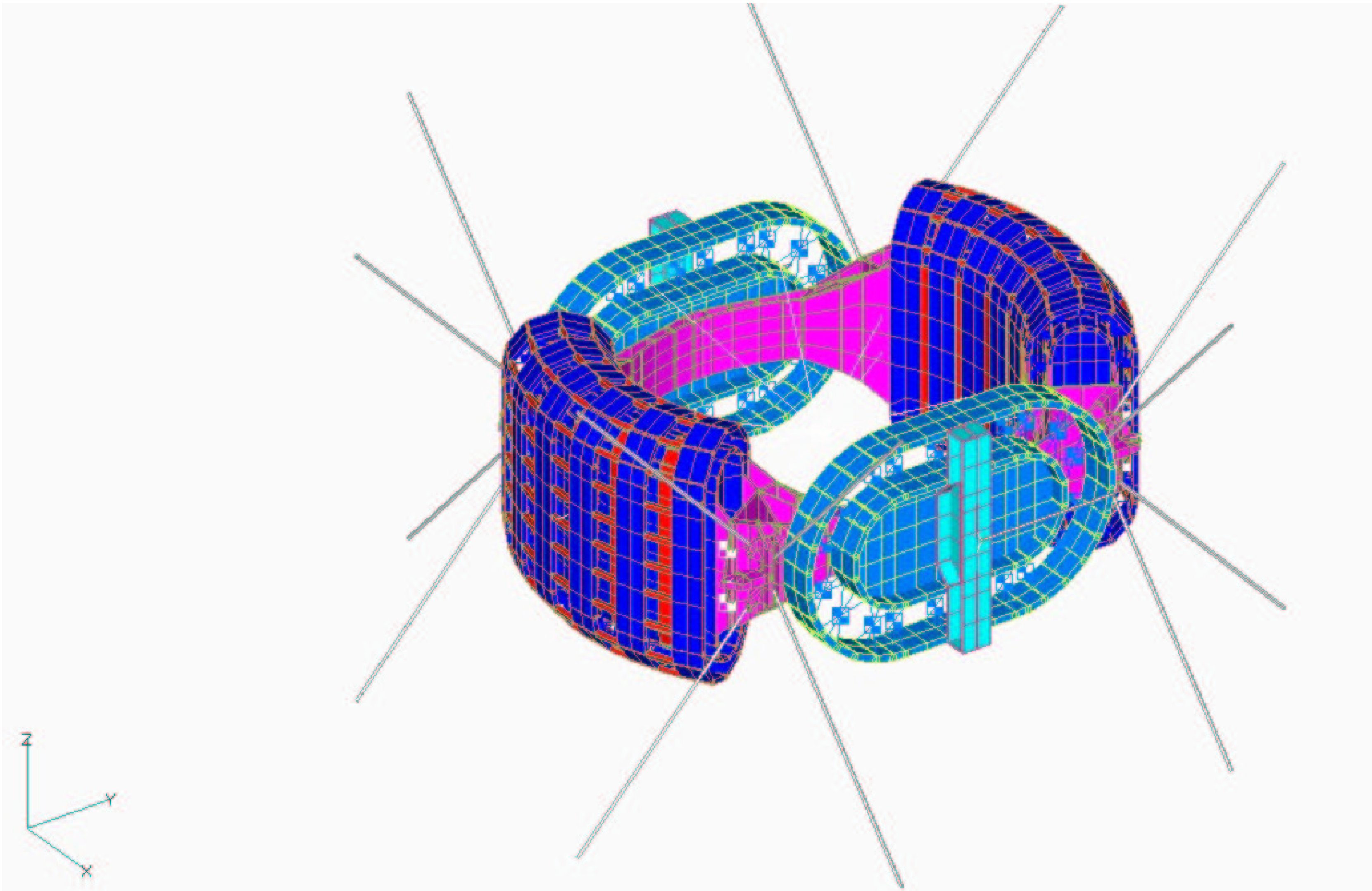
Loads Model of the Magnet



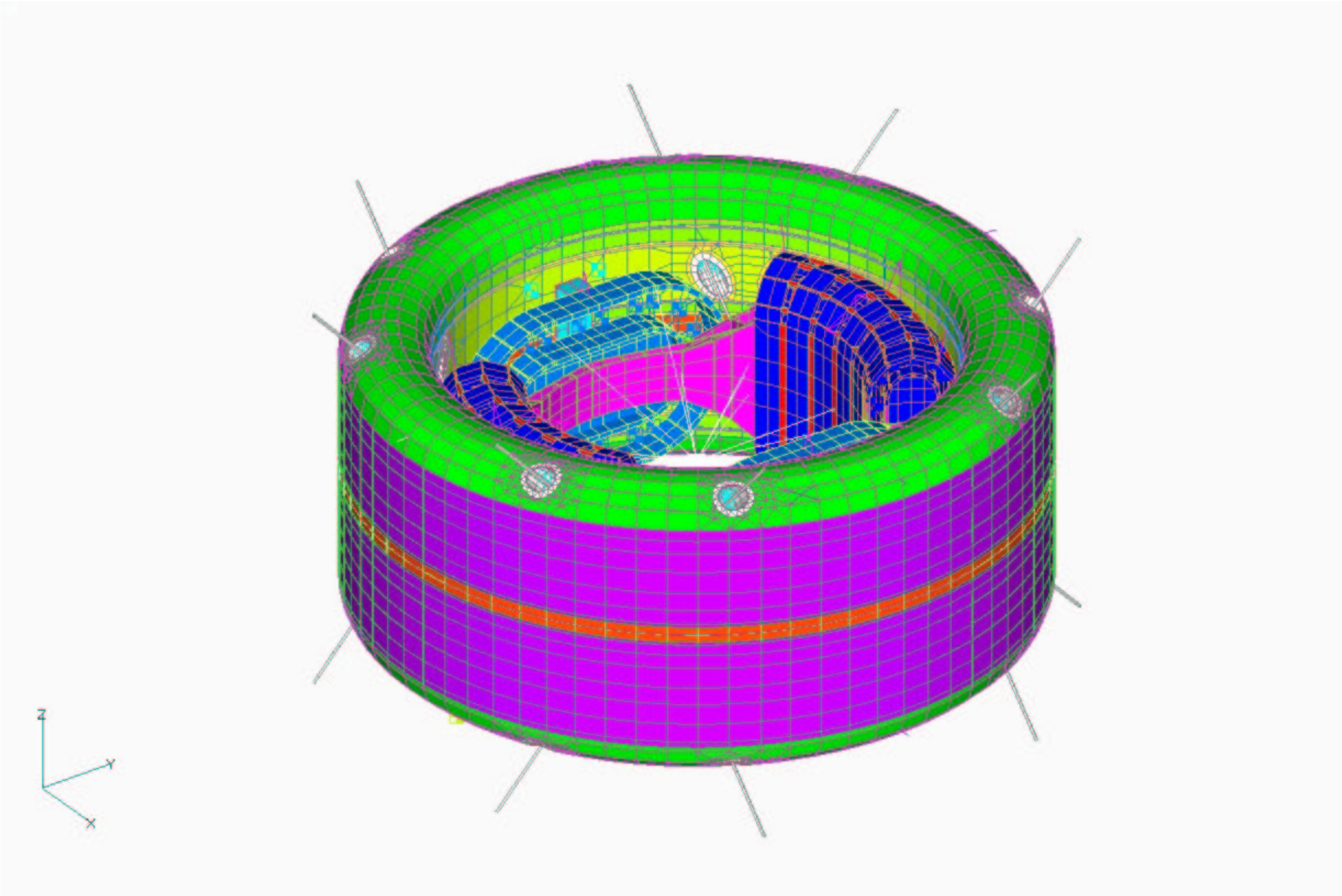
Loads Model of the Helium Tank



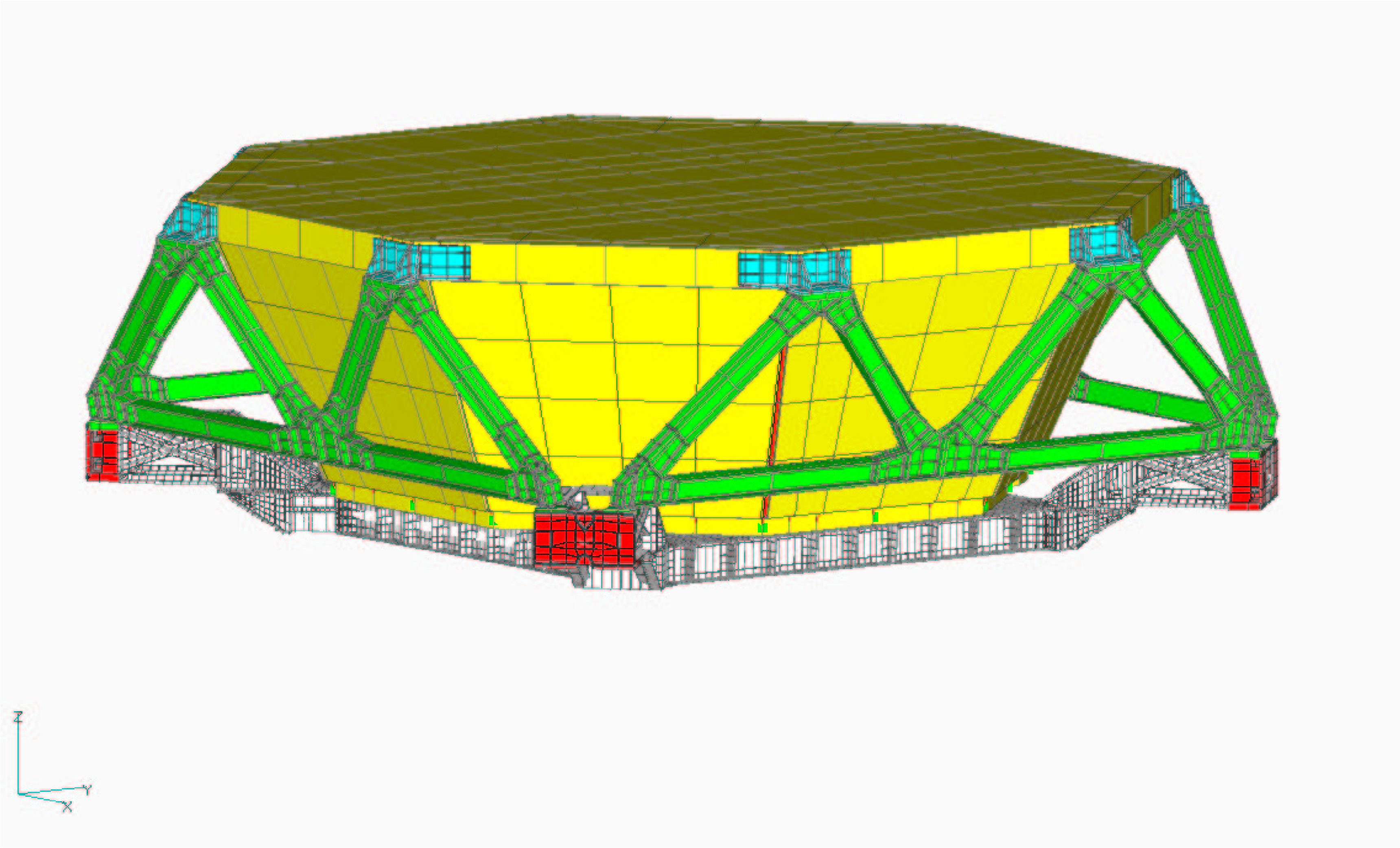
Loads Model of the Magnet showing Support Straps



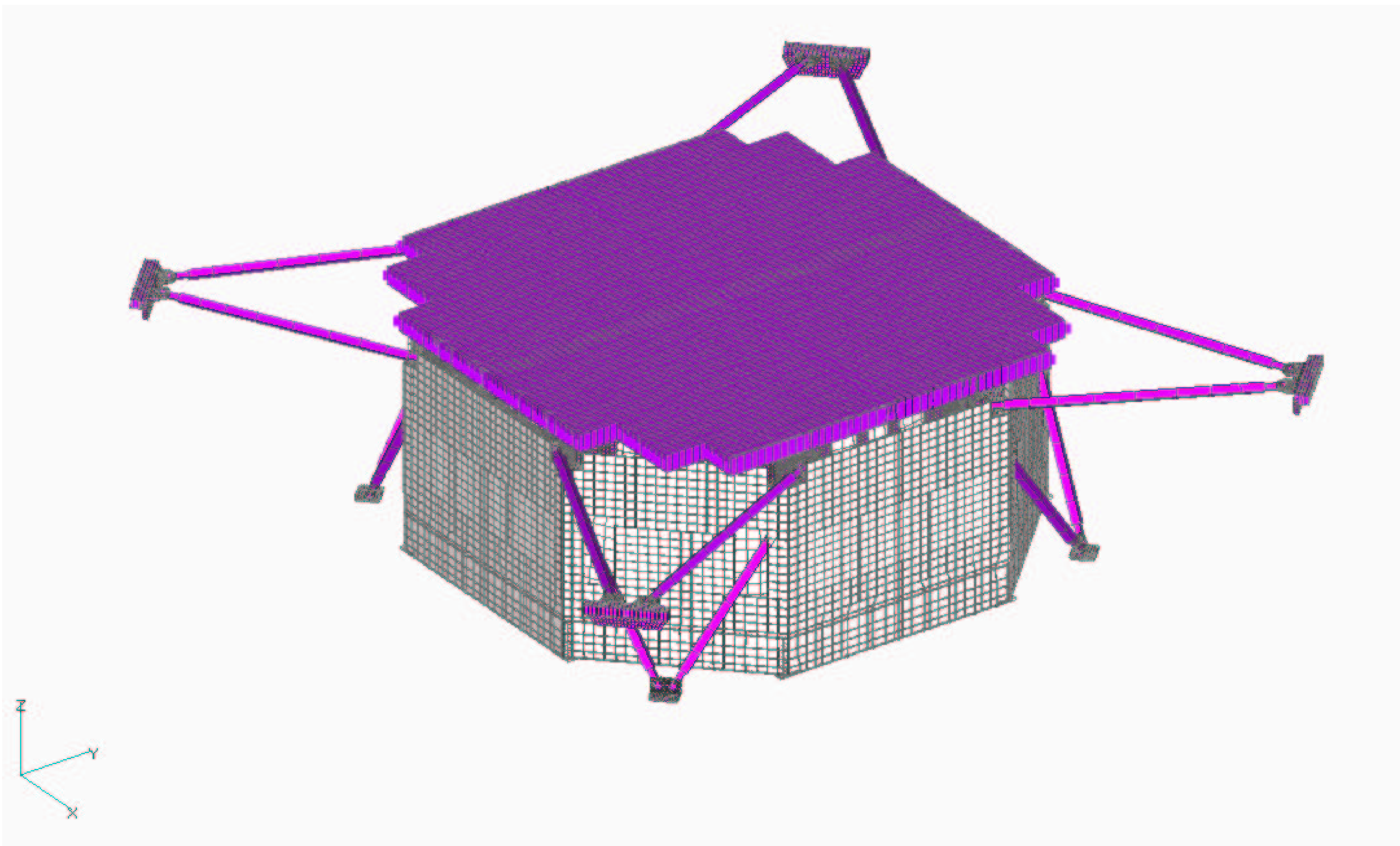
Loads Model of the Cryomagnet System



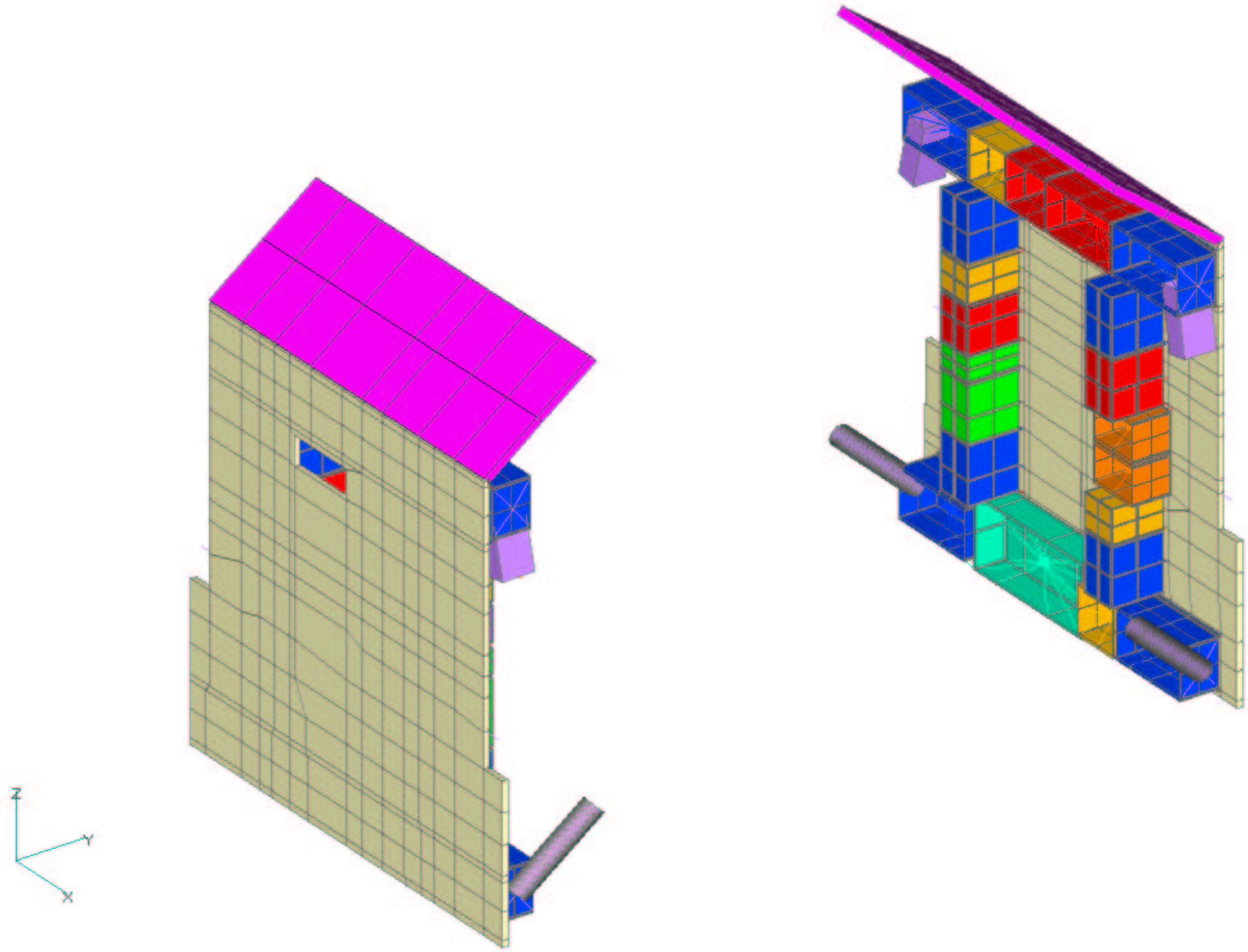
Loads Model of the TRD with Upper TOF



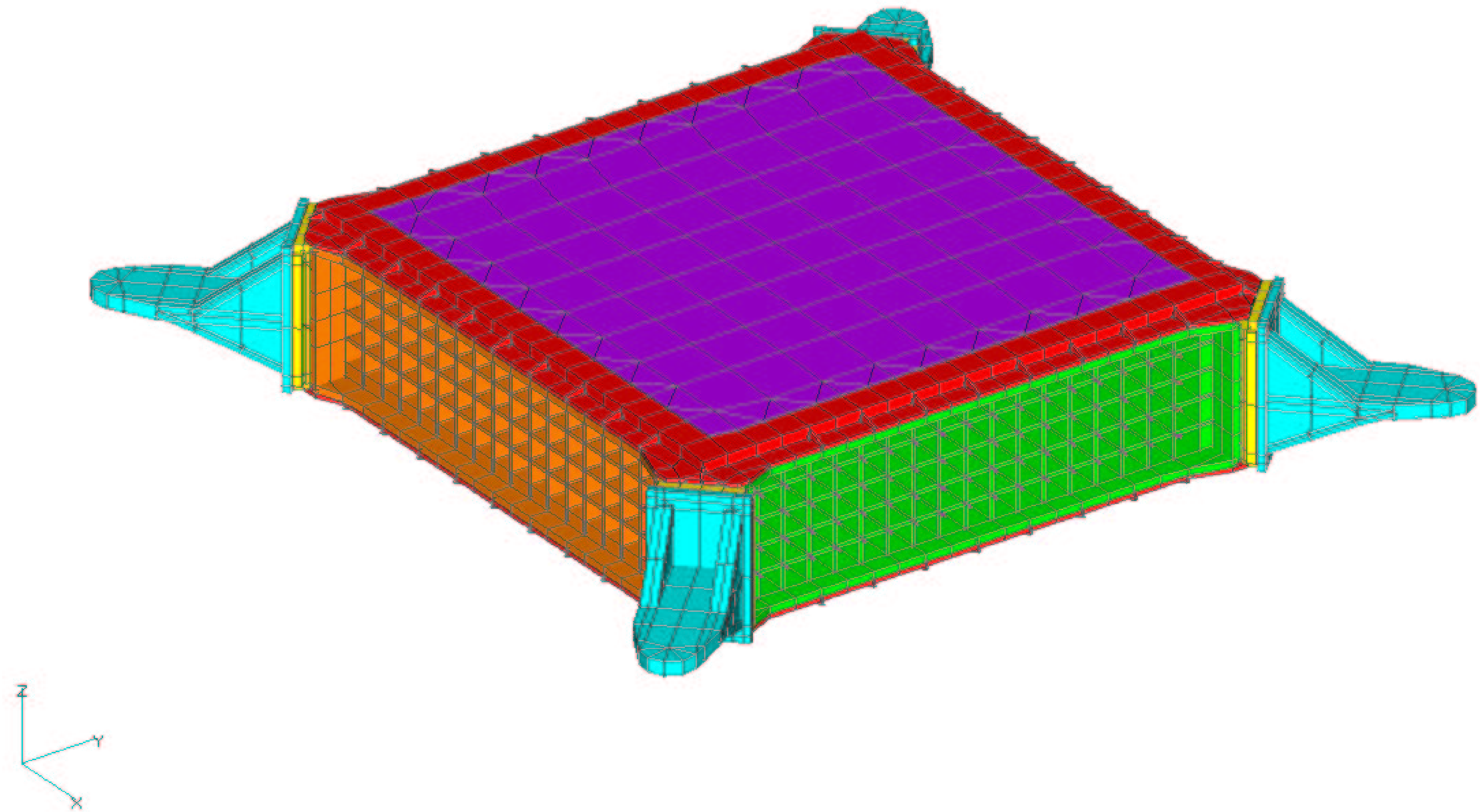
Loads Model of the Lower Time of Flight and RICH



Loads Model of the RAM/WAKE Radiators with Tracker Radiators



Loads Model of the ECAL



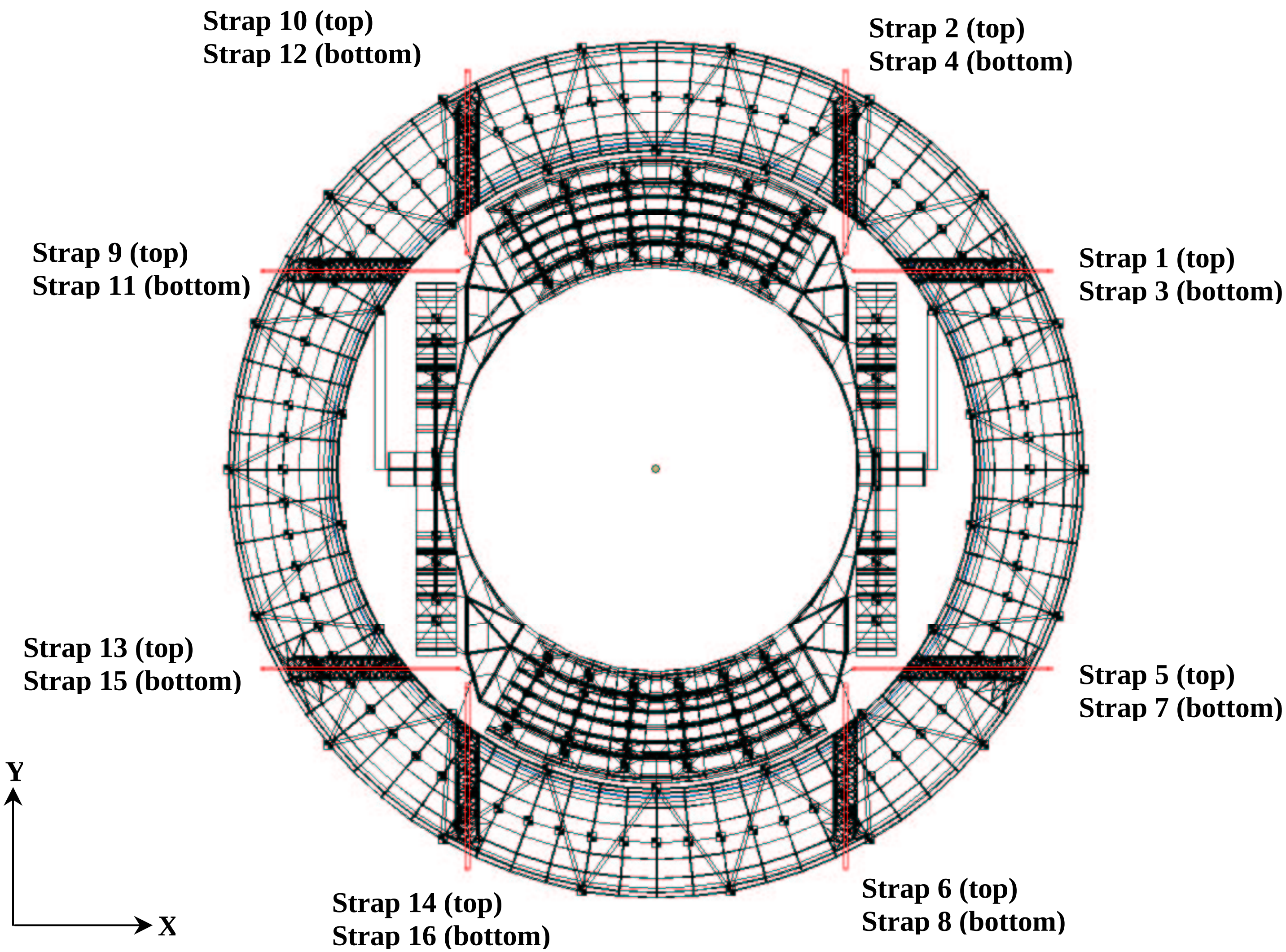
AMS-02 Static Preload

- **Static and dynamic loads analyses must account for the preload condition of the magnet support straps**
- **Preload is due to several factors**
  - Mechanical compression of Belleville washers and tensioning of straps during assembly
  - External pressure loads on vacuum case when internal vacuum is generated
  - Thermal loads: external vacuum case at ambient temperature, internal VC at 1.8 °K
  - Trunnion misalignment during installation into Orbiter cargo bay
  - Gravity increases upper strap load, decreases lower strap loads (configuration dependent as shown on next chart)

AMS-02 Static Preload

Strap ID	Strap Type	Liftoff Preload Condition		Nominal Landing Preload Condition		Abort Landing Preload Condition	
		Disp (inches)	Force (lbs)	Disp (inches)	Force (lbs)	Disp (inches)	Force (lbs)
90001	**C1W1**	0.809	1824.8	**0.852**	**2513.7**	**0.867**	**2773.0**
90002	**C2W2**	0.847	1908.1	0.798	1826.1	**0.865**	**2571.9**
90003	**C1W1**	0.796	1795.2	0.680	1539.9	0.816	1840.7
90004	**C2W2**	0.827	1864.3	0.628	1435.5	0.815	1836.5
90005	**C1W1**	0.810	1826.3	**0.852**	**2510.4**	**0.866**	**2742.3**
90006	**C2W2**	0.847	1909.2	0.797	1823.8	**0.864**	**2540.4**
90007	**C1W1**	0.792	1787.4	0.675	1530.0	0.811	1829.5
90008	**C2W2**	0.828	1865.9	0.629	1438.0	0.816	1839.5
90009	**C1W1**	**0.883**	**3526.2**	**0.852**	**2517.8**	**0.866**	**2747.2**
90010	**C2W2**	0.835	1882.8	0.798	1825.3	**0.864**	**2550.6**
90011	**C1W1**	**0.883**	**3511.0**	0.678	1536.1	0.815	1839.1
90012	**C2W2**	0.839	1890.8	0.629	1439.3	0.818	1843.7
90013	**C1W1**	**0.882**	**3484.5**	**0.852**	**2502.7**	**0.866**	**2756.8**
90014	**C2W2**	0.831	1873.8	0.800	1830.9	**0.865**	**2587.3**
90015	**C1W1**	**0.883**	**3502.9**	0.679	1537.4	0.817	1842.3
90016	**C2W2**	0.833	1876.4	0.627	1433.4	0.815	1835.5

AMS-02 Static Preload

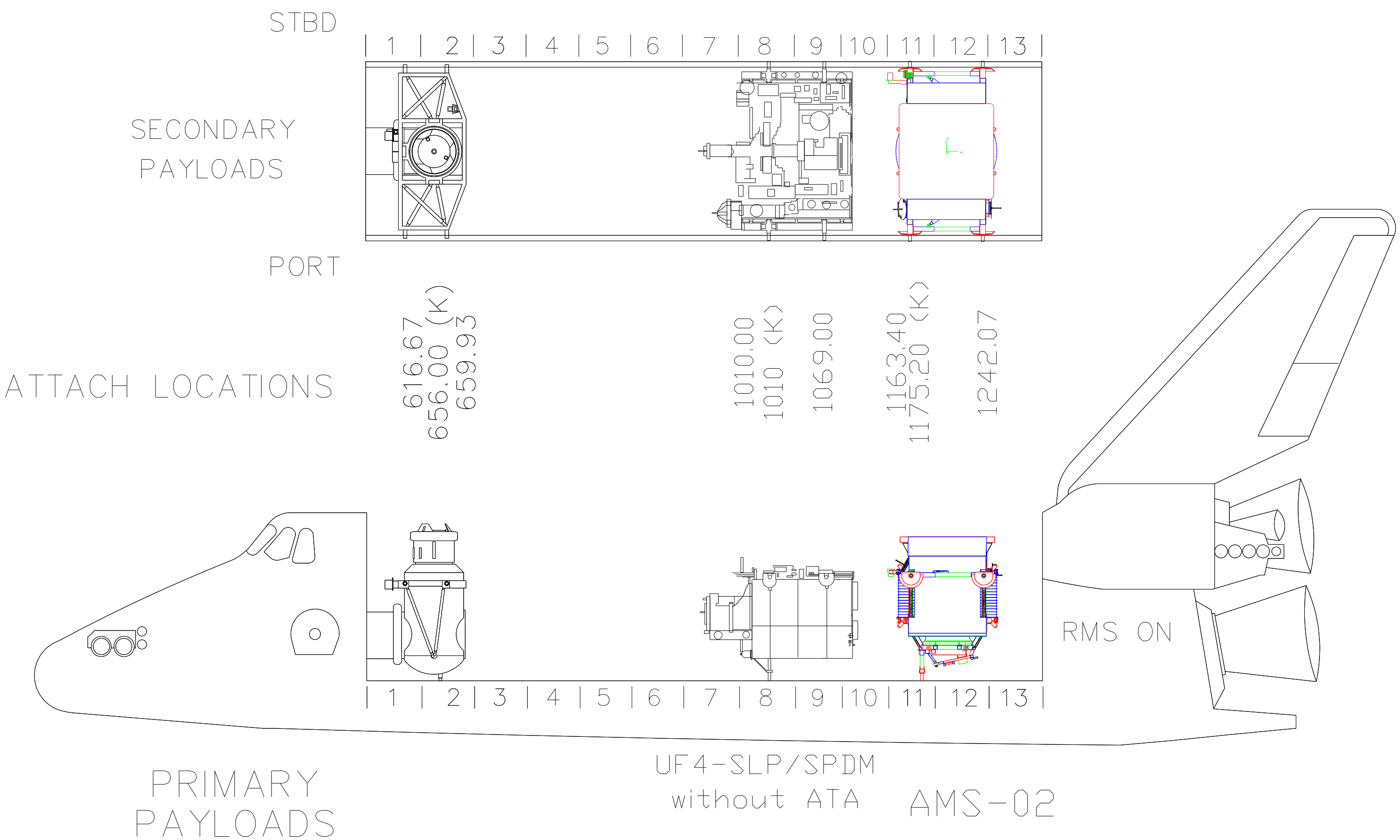


Flight Assignment Status for AMS-02

- June 1998 — Successful flight of AMS-01
- Oct 1999 — No flight manifested when initial designed coupled loads analysis was performed using generic forward/aft cargo bay locations
- June 2000 — At time of PDR, AMS-02 manifested for UF4 flight (STS-128), but no specific cargo bay location assigned
- Oct 2000 — UF4 manifest consisted of AMS-02 located at Xo 1175.20 (keel) and Spacelab Pallet with SPDM (no ATA) in midbay
- Nov 2002 — AMS-02 moved to UF4.1 flight (STS-127) with a cargo bay location of Xo 1010.0 (keel), co-manifested pallets not specified
- Jan 2003 — Xo 1010.0 (keel) location not capatible with interface loads capability, Boeing began ROEU compatibility assessment for two alternate locations in aft cargo bay
- May 2003 — Two locations currently being assessed by FAWG
    - Xo 1175.20 (keel) — preferred location
    - Xo 1167.33 (keel)

Requested Payload Bay Location for UF4.1

- Primary trunnion: x_o 1163.40, Stabilizer trunnion: x_o 1242.07, Keel trunnion: x_o 1175.20
- Satisfies ROEU compatibility requirements — extension to be made 6.07 inches longer
- AMS-02 interface loads are within the Orbiter attach point capability
- Clearances with ISS payload envelope and Orbiter hardware are being assessed



AMS-02 Interface Loads

Orbiter Interface Forces from Nonlinear Static Liftoff Analysis						
Attach Point	X Min (lbs)	X Max (lbs)	Y Min (lbs)	Y Max (lbs)	Z Min (lbs)	Z Max (lbs)
Stbd Primary	-56020.	+56420.	---	---	-55140.	+67390.
Port Primary	-53660.	+53740.	---	---	-65830.	+53540.
Stbd Stabilizer	---	---	---	---	-59560.	+47070.
Port Stabilizer	---	---	---	---	-45920.	+58420.
Keel	---	---	-24170.	+24110.	---	---

Orbiter Interface Forces from Nonlinear Static Nominal Landing Analysis						
Attach Point	X Min (lbs)	X Max (lbs)	Y Min (lbs)	Y Max (lbs)	Z Min (lbs)	Z Max (lbs)
Stbd Primary	-43850.	+43900.	---	---	-60260.	+72610.
Port Primary	-42020.	+42020.	---	---	-70770.	+58500.
Stbd Stabilizer	---	---	---	---	-63330.	+51040.
Port Stabilizer	---	---	---	---	-50140.	+62460.
Keel	---	---	-28460.	+28420.	---	---

Orbiter Interface Forces from Nonlinear Static Abort Landing Analysis						
Attach Point	X Min (lbs)	X Max (lbs)	Y Min (lbs)	Y Max (lbs)	Z Min (lbs)	Z Max (lbs)
Stbd Primary	-46310.	+46200.	---	---	-63320.	+75650.
Port Primary	-44770.	+44810.	---	---	-73850.	+61560.
Stbd Stabilizer	---	---	---	---	-65870.	+53590.
Port Stabilizer	---	---	---	---	-52610.	+65180.
Keel	---	---	-30300.	+30300.	---	---

AMS-02 Orbiter Attach Point Limit-Load Capability Assessment

- Payload bay location for UF4.1 current manifest option
  - **Primary trunnions:** **X_o 1155.53**
  - **Keel trunnion:** **X_o 1167.33**
  - **Stabilizer trunnions:** **X_o 1234.20**
- Three payload configurations analyzed using latest AMS-02 math model (version 2-03)
  - Liftoff (full helium tank) – payload weight of 14809. lb
  - Nominal landing (empty helium tank) – payload weight of 14000. lb
  - Abort landing (full helium tank) – payload weight of 14809. lb
- Interface forces computed using nonlinear static analysis with design load factors
  - Analysis accounts for preloads in payload (including trunnion misalignment)
  - Liftoff: $Nx = \pm5.7$ $Ny = \pm1.6$ $Nz = \pm5.9$ $Rx = \pm10.$ $Ry = \pm25.$ $Rz = \pm18.$
  - Landing: $Nx = \pm4.5$ $Ny = \pm2.0$ $Nz = \pm6.5$ $Rx = \pm20.$ $Ry = \pm35.$ $Rz = \pm15.$
- Orbiter attach point capability was exceeded
  - **Liftoff:** **lateral load capability at forward attach point exceeded by 4%**
  - **Nominal landing:** **lateral load capability at forward attach point exceeded by 16%**
  - **Abort landing:** **lateral load capability at forward attach point exceeded by 19%**
- Typically, time-consistent loads from coupled transient analyses show significant reduction compared to maximum static-load combinations
- Completion of coupled transient analyses using latest AMS-02 math models may allow reduction of uncertainty factor from 1.5, thus reducing loads within Orbiter attach-point capability

AMS-02 Orbiter Attach Point Limit-Load Capability Assessment

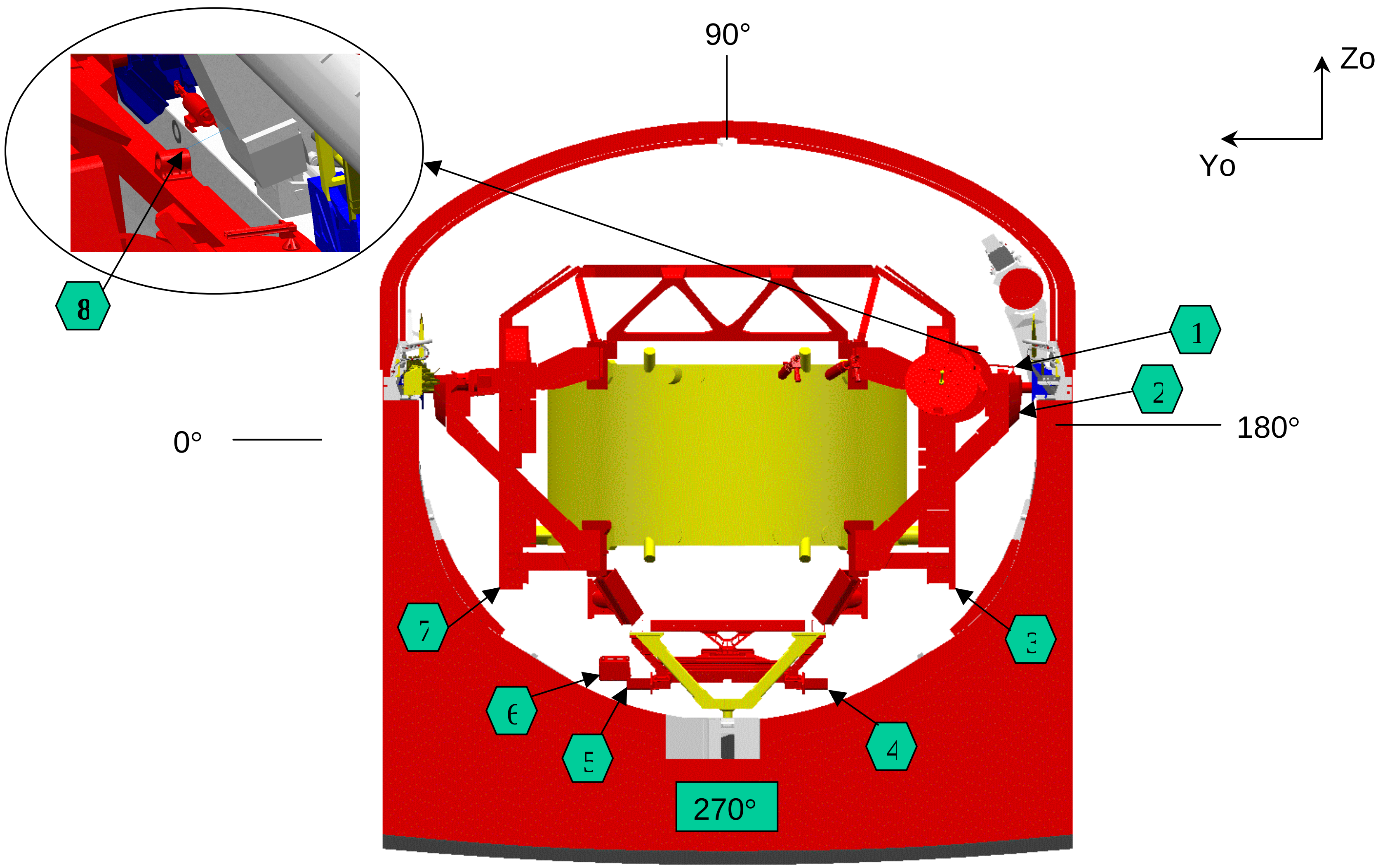
- Requested payload location for for UF4.1
  - **Primary trunnions:** **X_o 1163.40**
  - **Keel trunnion:** **X_o 1175.20**
  - **Stabilizer trunnions:** **X_o 1242.07**
- Three payload configurations analyzed using latest AMS-02 math model (version 2-03)
  - Liftoff (full helium tank) – payload weight of 14809. lb
  - Nominal landing (empty helium tank) – payload weight of 14000. lb
  - Abort landing (full helium tank) – payload weight of 14809. lb
- Interface forces computed using nonlinear static analysis with design load factors
  - Analysis accounts for preloads in payload (including trunnion misalignment)
  - Liftoff: Nx = ±5.7 Ny = ±1.6 Nz = ±5.9 Rx = ±10. Ry = ±25. Rz = ±18.
  - Landing: Nx = ±4.5 Ny = ±2.0 Nz = ±6.5 Rx = ±20. Ry = ±35. Rz = ±15.
- Orbiter attach point capability is adequate
  - **Liftoff:** **all load cases within Orbiter capability**
  - **Nominal landing:** **all load cases within Orbiter capability**
  - **Abort landing:** **all load cases within Orbiter capability**
- Load capability ratios expected to increase if time-consistent loads from coupled transient analyses are used

AMS-02 Orbiter Clearance Assessment

- Results from presentation entitled “AMS-02 and Orbiter Payload Bay Static and Dynamic Clearance Assessment” by Karen Bellard, Gilmar Gonzalez, and Charles Hethcoat of Boeing, April 29, 2003
- AMS-02 cargo bay location based on ROEU compatibility assessment by Gilmar Gonzalez, Boeing
  - Primary Trunnion Xo 1155.53
  - Stabilizing Trunnion Xo 1234.20
  - Keel Trunnion Xo 1167.33
- Assumptions for dynamic clearance assessment
  - Manufacturing tolerance of 0.1 inch
  - Thermal growth of 0.5 inch
  - Relative dynamic motion of 3.0 inch at all locations except scuff plates
- All items show “acceptable clearance” except for PAS guide pins which show “close clearance”
- Dynamic clearance will be reassessed when displacement data is available from dynamic analyses

	Payload Hardware	**Orbiter Hardware**	**Xo Location**	**Yo Location**	**Zo Location**	**Hardware Outer Radius (inches)**	**Hardware Angle (deg)**	**Static Clearance (inches)**	**Dynamic Clearance (inches)**
1	EVA Handrail	Latch Bridge	1156.01 1234.68	-87.58	418.10	89.43	168.32	5.39	1.70
2	Scuff Plate	Latch Bridge	1155.53 1234.20	±89.50	414.04	90.59	171.08	3.00	Not available
3	Port Radiator Panel	Orbiter Wire Tray	1191.00	-69.41	348.84	86.23	216.39	6.98	3.29
4	Port PAS Guide Pin	Closeout Blanket	1183.03	-30.51	316.33	89.06	249.97	4.41	**0.72**
5	Stbd PAS Guide Pin	Closeout Blanket	1183.03	30.51	316.33	89.06	290.03	4.41	**0.72**
6	UMA	Closeout Blanket	1207.95	38.34	319.23	89.41	295.39	7.43	3.74
7	Stbd Radiator Panel	Orbiter Wire Tray	1191.00	69.41	348.84	86.23	323.61	6.98	3.29
8	Wif Socket	MPM	1187.47	-85.45	419.85	87.73	166.93	5.06	1.37

AMS-02 Orbiter Clearance Assessment



AMS-02 Loads Analyses

- **Primary analyses required**
  - Nonlinear static for loads and stress assessment (NASTRAN)
  - Nonlinear transient (NASTRAN)
    - Pre-test analysis for sine sweep of STA VC and CMR
    - Coupled loads analysis for Shuttle liftoff and landing
  - Quasi-static loads analysis for deflection and clearance assessment
  - Buckling for vacuum case and helium tank design verification
- **Frequency response and modal analysis of nonlinear preloaded model** (NASTRAN)
- **Acoustic analysis of components with large honeycomb panels** (VAPEPS)
- **Fracture and fatigue analyses** (NASA FLAGRO)
- **Development of ‘equivalent linear system’ math model**
  - Linear model is highly desirable for Verification Loads Analysis
  - Facilitates parametric studies for better understanding of system response

AMS-02 Maximum Trunnion Displacements

- Based on nonlinear, static analysis with design load factors (with 1.5 uncertainty factor)
- Stabilizer trunnion has enforced displacement of 0.2 inches for z-axis to represent misalignment during Orbiter installation (noted by * for load condition)

LOCATION	Max X Disp (inches)	Max Y Disp (inches)	Max Z Disp (inches)	Load Condition
Primary Trunnion	constrained	0.273	constrained	Abort landing
Stabilizer Trunnion	0.092	0.201	0.200	Liftoff case 1*
	0.094	-0.146	constrained	Liftoff case 2
	-0.019	**0.317**	0.200	Abort landing case 1*
	0.034	0.301	constrained	Abort landing case 2
Keel Trunnion	**1.010**	constrained	0.056	Liftoff
	-0.626	constrained	**0.149**	Abort landing

Linear Couple Transient Analysis Results

- **Initial linear coupled loads analysis (CLA) performed in October 1999**
  - Math model --- many components were modeled with low fidelity or as lumped masses
  - Linear analysis
  - Generic manifest --- AMS payload in two payload bay locations (mid-bay and aft-bay)

- **Current linear coupled loads analysis (CLA)**
  - Math model --- most components are modeled with high fidelity
  - Linear analysis --- uses upper region stiffness for magnet support straps
  - UF4 manifest
    - AMS payload in bays 11/12 (keel x_o 1175.20)
    - Spacelab pallet in midbay location
  - Three load factor values increased, but all remain within current design load

Load Case	Component	1999 CLA	2003 CLA	Design Loads
Liftoff	N_x (g's)	-3.9 +0.3	-3.4 +1.0	± 5.7
	N_y (g's)	-0.7 +0.7	-0.8 +0.5	± 1.6
	N_z (g's)	-4.4 +4.3	-2.2 +1.3	± 5.9
Landing	N_x (g's)	-1.7 +1.6	-1.5 +1.3	± 4.5
	N_y (g's)	-1.1 +1.3	-0.8 +1.1	± 2.0
	N_z (g's)	-1.5 +4.8	-2.6 +3.9	± 6.5

Nonlinear "Modes" for AMS-02 Liftoff Configuration

- **Based on modal analysis using the stiffness for the preload condition**
  - Assumes payload is constrained at orbiter attach points
  - Assumes strap stiffness remains constant at preloaded condition
  - Response at these frequencies occurs only if excitation force is low and does not change the preload

Mode No.	Frequency (Hz)	Mode Description
1	**4.03**	Y-axis translation of cryomagnet system
2	**5.75**	Y-axis rotation of cryomagnet system
3	**8.52**	Z-axis rotation of cryomagnet system
4	**9.81**	X-axis translation of cryomagnet system
5	**11.51**	X-axis rotation of cryomagnet system
6	**13.23**	Y-axis translation of full payload, cryomagnet system moving out-of-phase
7	**15.28**	Y-axis rotation of full payload, out-of-phase motion of cryomagnet system along x-axis
8	**16.32**	Y-axis rotation of full payload, in-phase rotation of cryomagnet system about y-axis
9	**16.82**	Z-axis translation of VC/upper payload, lower body lateral motion, y-axis rotation of cryomagnet
10	**19.37**	Y-axis translation of cryo system, magnet and helium tank have out-of-phase motion
11	**23.56**	Vertical motion of USS/VC and cryomagnet system, lateral bending of ram/wake radiators
12	**24.36**	Combined motion of USS/VC/radiators, very little participation of cryomagnet system
13	**24.48**	Combined motion of USS/VC/radiators, very little participation of cryomagnet system
14	**26.51**	Combined motion of USS/VC/radiators, very little participation of cryomagnet system
15	**27.83**	Port tracker radiator bending mode
16	**28.70**	Starboard tracker radiator bending mode
17	**29.45**	Combined motion of USS/VC/radiators, magnet and helium tank out-of-phase x-axis translation
18	**30.61**	Vertical motion of full payload, symmetrical (in-phase) bending of radiators
19	**35.70**	First flexure mode of helium tank
23	**38.18**	First flexure mode of upper TOF (drum head mode)

Nonlinear "Modes" for AMS-02 Landing Configurations

- **Based on modal analysis using the stiffness for the preload condition**
    - Assumes payload is constrained at orbiter attach points
    - Assumes strap stiffness remains constant at preloaded condition
    - Response at these frequencies occurs only if excitation force is low and does not change the preload
- **Nominal landing assumes empty helium tank and warm straps**
- **Abort landing assumes full helium tank and cold straps**

Mode No.	Nominal Landing		Abort Landing	
	Freq. (Hz)	**Mode Description**	**Freq. (Hz)**	**Mode Description**
1	**4.50**	Y-axis translation of cryomagnet	**7.62**	Y-axis translation of cryomagnet
2	**5.51**	Y-axis rotation of cryomagnet	**8.17**	Payload X trans, magnet y rotation
3	**11.83**	Payload pitch, magnet Y rotation	**11.05**	Magnet Z rotation
4	**11.91**	Payload pitch, magnet Z rotation	**11.94**	Payload and magnet Z rotation
5	**13.26**	Y translation, payload & magnet out-of-phase	**12.64**	Y trans payload, X rotation magnet
6	**16.20**	Payload Z trans, magnet X rotation	**16.11**	Z trans payload and magnet
7	**16.45**	Magnet X rotation	**16.31**	Z trans payload and magnet
8	**17.21**	Payload & magnet Z translation	**16.50**	Y trans payload and magnet, He tank out-of-phase
9	**22.80**	Combined payload motion	**19.37**	Combined payload motion
10	**24.09**	Combined payload motion	**22.72**	Combined payload motion

Nonlinear Transient Analysis Methodology

- **Nonlinear transient analysis performed with MSC Nastran Version 70.7 and 2001**
  - Capability has been carefully tested using smaller models and sample problems
  - Working closely with MSC Technical Support to resolve issues with software
- **Direct integration required instead of "traditional" modal approach**
  - Using fixed time-step (typically 0.0001 seconds) to satisfy convergence criteria
  - Nastran adaptive algorithm was investigated but results were not acceptable
- **Substructuring (superelements) is required due to size of math model**
  - Shuttle components modeled with external superelement (shuttle, ODS, RMS)
  - Currently using external superelement for Spacelab pallet (provided by Boeing, Huntsville)
  - AMS-02 currently divided into two superelements (modal reduction to 100 Hertz)
  - Residual includes magnet support straps and boundary from superelements
- **Diagonal system damping can not be used**
  - Currently using 2% uniform structural damping (equivalent to viscous damping at 10 Hz)
  - Investigating alternatives for damping
    - Modal damping on superelements and structural damping on straps
    - Component specific damping transformed to system level (fully populated matrix)
- **Loads consist of transient loads only (liftoff/landing load cases provided by Boeing)**
  - Static preload of magnet support straps represented by a shifted stress-strain curve
  - Static preload for remainder of structure added to transient results in post-processing

Nonlinear Transient Analysis Status

- **Nonlinear transient analysis capability is currently being used to perform pretest analysis for the STA VC/CMR sine sweep test**
- **Nonlinear transient analysis capability is available for landing analysis of coupled Orbiter/payload**
  - Some anomalies with superelement data recovery are currently being investigated
  - Checkout and validation expected to be completed soon
- **Nonlinear transient analysis capability is available for liftoff analysis of coupled Orbiter/payload**
  - Some anomalies with superelement data recovery are currently being investigated
  - Large rigid-body motion inherent to model configuration appears to be causing inaccuracies in data recovery process (using displacement method)
  - Several techniques to mitigate/eliminate the problem are being assessed
    - Routine that removes rigid-body motion during integration process
    - Base-drive of AMS payload using interface accelerations from coupled analysis
  - Checkout and validation process is continuing

Current Nonlinear Transient Results

- **Comparison of strap loads for liftoff cases**

Strap ID	Static Design Loads Results for Liftoff		Liftoff Case lo1001 (nonlinear transient with damping)		Liftoff Case lo1001 (nonlinear transient without damping)	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
1	977.3	21302.4	1497.0	1866.4	1287.2	8036.7
2	1340.6	17982.5	1751.9	5930.4	1482.0	13883.5
3	1026.3	22039.2	1565.7	2211.6	1292.1	10031.2
4	1252.6	17186.6	1737.3	5305.1	1408.1	13800.4
5	965.5	21682.8	1542.2	1868.8	1203.1	9800.0
6	1327.1	18129.8	1744.1	5771.8	1429.8	13883.5
7	1000.2	22517.6	1542.8	1975.9	1219.9	9463.5
8	1256.4	17388.1	1703.2	6063.2	1380.5	14039.9
9	1047.4	**20111.9**	2562.5	**9226.5**	1710.2	**19793.7**
10	1261.3	17152.9	1723.9	5198.4	1541.5	14542.8
11	1007.0	**21466.0**	3275.6	**9191.0**	1571.4	**18051.9**
12	1220.4	16754.8	1727.1	5373.7	1460.9	10182.6
13	1016.4	**20739.8**	2715.5	**8305.2**	1684.0	**15765.0**
14	1266.3	17338.6	1743.1	5650.1	1489.5	11096.6
15	989.0	**21977.2**	3257.7	**8276.2**	1507.3	**19587.3**
16	1214.0	17008.0	1715.8	5423.4	1456.4	10630.3

Current Nonlinear Transient Results

- **Comparison of strap loads for nominal landing cases**

Strap ID	Static Design Loads Results for Nominal Landing		Nominal Landing Cases LF7030-LF7036 (nonlinear transient with damping)	
	Minimum	Maximum	Minimum	Maximum
1	567.3	**19440.1**	1702.4	**9428.2**
2	799.8	16334.4	1363.7	8760.8
3	553.1	20005.7	1040.9	4595.0
4	690.6	16171.5	1085.5	1808.4
5	553.6	**19810.7**	1707.3	**9318.9**
6	784.2	16666.0	1555.5	7308.9
7	524.1	20426.3	1029.5	3493.5
8	685.8	16499.2	943.7	2866.8
9	619.8	**18664.6**	1498.3	**11195.6**
10	754.8	15482.5	1360.6	8843.3
11	547.3	19491.3	984.4	9373.3
12	668.7	15718.3	978.5	3757.3
13	586.7	**19168.1**	1541.9	**12035.7**
14	754.5	15585.6	1385.4	9249.2
15	528.7	19954.1	1017.8	8358.4
16	657.3	16031.4	1029.4	4088.2

Current Nonlinear Transient Results

- **Comparison of strap loads for abort landing cases**

Strap ID	Static Design Loads Results for Abort Landing		Abort Landing Case LF7030 (nonlinear transient with damping)	
	Minimum	**Maximum**	**Minimum**	**Maximum**
1	996.2	**21303.7**	2237.3	**7612.9**
2	1278.5	**19522.5**	2098.5	**6840.1**
3	1026.3	22081.3	1657.2	3293.8
4	1252.6	18751.4	1695.9	1958.0
5	965.5	**21719.4**	2169.1	**7556.2**
6	1327.1	**19796.8**	2054.2	**6733.6**
7	1000.2	22529.7	1644.8	3223.1
8	1256.4	19121.5	1698.0	1961.3
9	1047.4	**19705.6**	2065.0	**7742.8**
10	1261.3	**18601.7**	1985.9	**8501.4**
11	1007.0	21345.1	1607.8	3260.0
12	1220.4	18388.3	1650.1	2414.6
13	1016.4	**20343.4**	2110.5	**7747.4**
14	1266.3	**18968.1**	2049.8	**8417.2**
15	989.0	21876.0	1613.1	3438.0
16	1214.0	18728.7	1640.9	2288.8